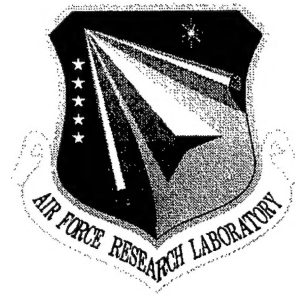


AFRL-IF-RS-TR-1999-126
Final Technical Report
June 1999



EMBEDDED SIGNAL PROCESSOR FOR UUV APPLICATIONS

Sanders, A Lockheed Martin Company

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EMBEDDED SIGNAL PROCESSOR FOR UUV APPLICATIONS

Les Spain

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1. ABSTRACT

This document is to serve the CDRL A004 and A009 requirements of a final report for the UUVSP program.

The Objectives of the Unmanned Undersea Vehicle (UUV) program was to provide High Performance Scaleable Computing (HPSC) technology developed at Lockheed Martin in a scaleable 24 GFLOP HPSC processor for 21 inch UUV applications. The demonstration platform was to extend prior work that was done under Martin Labs (now integrated with Lockheed Sanders) for NUWC (the DAP system) by integrating HPSC technology to transform the DAP system into a real time embedded system suitable for UUVSP applications.

It was decided that Naval Undersea Warfare Center (NUWC) would provide bottom-mapping algorithms for this demonstration. This algorithm was known as the Bathymetric Algorithm. This algorithm was provided to Sanders as a C program that ran on a UNIX workstation. Sanders was responsible for tailoring this algorithm into a scaleable process. The algorithm was tailored to use the Wideband Computers Inc. ADSP-21K Optimized DSP Library, and technology developed under the HPSC program for moving information between processing resources.

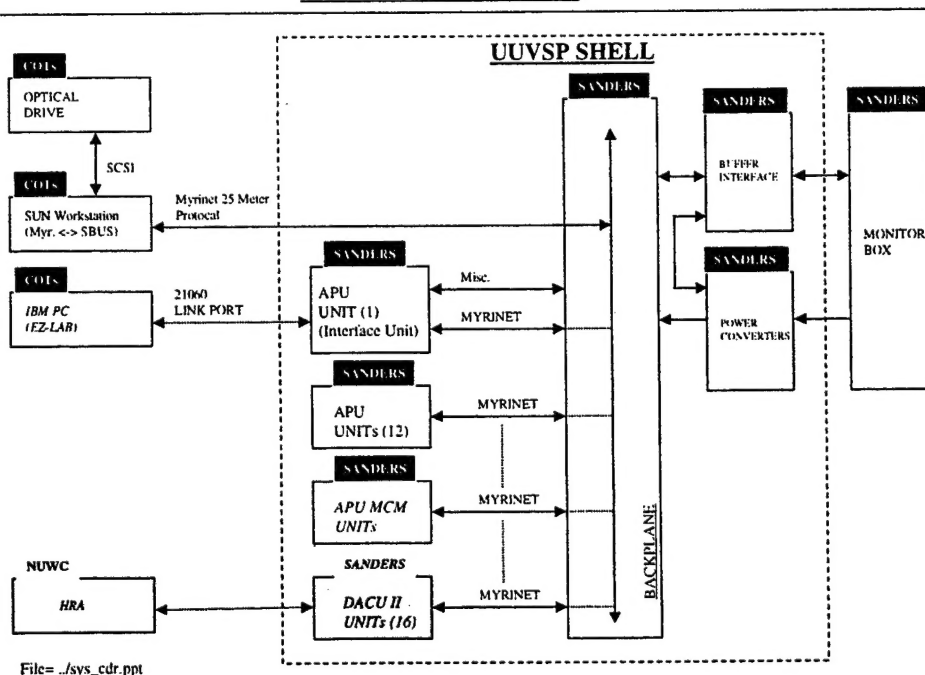
2. HARDWARE DEVELOPMENT

2.1 SYSTEM DIAGRAMS

The system was to be a demonstration system of embedded HPSC technology for UUVSP applications. The first phase of the "proof of concept" to extend HPSC technology into the UUVSP application arena, was to process "DAP data" in real time in a 24 GFLOP HPSC system. The 24 GFLOP system was to be formed factored into a representative UUVSP system. DAP data consists of previously captured digitized data from an HRA system.

2.1.1 ELECTRICAL FUNCTIONAL

SYSTEM BLOCK DIAGRAM



2.1.1.1 SYSTEM OPERATIONAL MODE

2.1.1.1.1 SUMMARY

Lockheed Sanders was to develop the hardware listed above in figure 2.1.1. The equipment that Lockheed Sander's was task to develop is labeled as "SANDERS". The Sander's developed hardware was to demonstrate an embedded 24 GFLOPS system.

The Sander's hardware was to be integrated with "COTS" hardware that would have provided for data injection of DAP data into the embedded 24 GFLOP system. The injected data would be distributed to the APU modules which would provide data processing on the DAP data. The resultant data would be sent back to the COTS hardware platform to verify the processing results.

2.1.1.1.2 APU MODULES

The APU modules were a thermally core processing module consisting of 16 ADSP-21060, 40 MHz floating point DSPs. Each module was capable of 2 GFLOPS processing. Each module consumed on average about 25 watts of power (@3.3 VDC) and provided 1280 Mbytes / Sec communication transfer to the UUVSP back plane.

The modules are thermally and physically capable of scaling to a 4 GFLOP module utilizing Quad SHARC MCMs built by Analog Devices. It was intent of the program that if early success and funding allowed, a MCM version of the APU modules would have be built and demonstrated in the system.

2.1.1.1.3 DACU UNITS

DACU units (Digitizing Analog Control Units) were not to be developed in this phase of the UUVSP program. The DACU units would be responsible for interfacing to the HRA unit, digitizing the data, formatting the data, and passing the data to the APU units for processing. This phase of the program was to size the DACU modules, provide resources in the system to allow for future development and insertion of the units. The DACU units would be necessary to achieve an integrated real time system with the HRA.

2.1.1.1.4 BACK PLANE

The UUVSP back plane provided for 32 module slots. 16 module slots were dedicated for APU module units. 16 module slots were dedicated for DACU module units. The UUVSP back plane was an active back plane based on Myrinet XBAR-8 Port switch technology.

2.1.1.1.5 POWER CONVERSION

The power conversion section was responsible for generating the local DC voltage needed by the local electronics in the UUVSP shell. It generated local +5.0 VDC, +3.3VDC, and +1.2 VDC. The power conversion section was used to convert the local DC electronic voltages needed from a tethered +300 VDC. The program used COTS DC-DC modules for this function.

The power conversion unit also allocated necessary resources for the integration of the DACU modules and the HRA front end. Both thermals, electrical and physical allocation was set aside for this additional functionality.

2.1.1.1.6 BUFFER INTERFACE

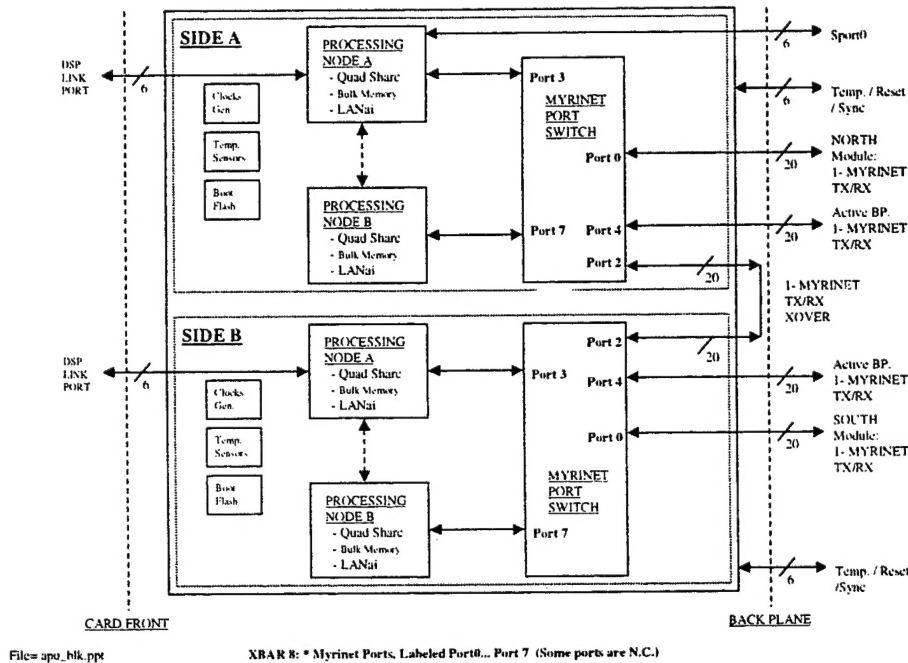
The buffer interface PWB was used to isolate signals between the monitor box unit and the UUVSP shell unit. The UUVSP shell electronics (APU, DACU, and HRA units) are at a floating ground potential to the monitor box unit by design. The buffer card served as a low cost interface to prevent damage that might have resulted from the floating ground configuration.

2.1.1.1.7 MONITOR BOX.

The monitor box unit provided for +300 VDC power generation to the UUVSP shell. The monitor box also provided for controlled power on / off state flow, status indicators, and simple monitoring of system health associated with power, temperature, and leak detection.

2.2 MODULE DIAGRAM

2.2.1 APU MODULES

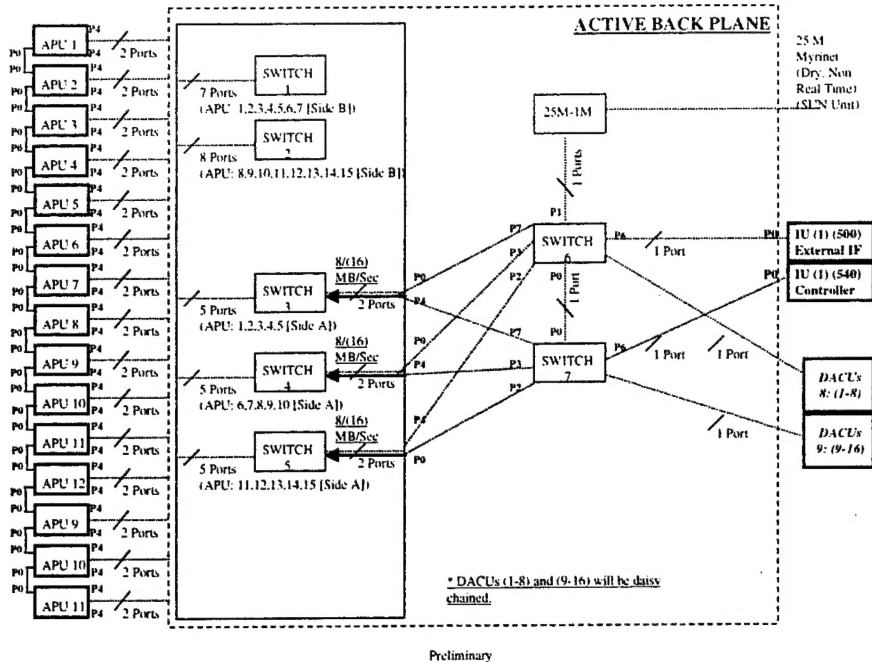


2.2.1.1 MODULE DESCRIPTION

Each APU module consisted of 16 ADSP21060 DSP arranged in clusters of 4 DSPs per node. There are 4 processing clusters per each APU module. Each processing cluster or node connects to 32 Mbytes of shared synchronous DRAM (SDRAM) with a shared LANai interface. The LANai, SDRAM and DSPs interfaces via the ADSP21060 data bus that operates at 40 MHz, 32 bits wide, yielding a bus data rate of 160 Mbytes / sec. Each DSP runs at 40 MHz, at +3.3 VDC operations, and with a peak performance of 120 MFLOPS per second. The LANai operates at 40 MHz, providing an interface to the back plane Myrinet network. The LANai interfaces to the back plane network with a data transfer rate of 160 Mbytes / Sec. Each module has 4 Myrinet LAN connections to the back plane, providing for a total back plane interface bandwidth of 1280 Mbytes / sec per APU module.

2.2.2 BACK PLANE MODULE

MYRINET BACK PLANE TOPOLOGY



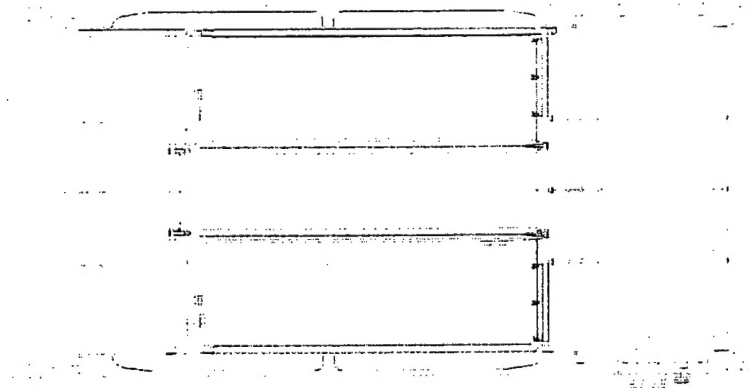
2.2.2.1 MODULE DESCRIPTION

The UVSP back plane unit was an active back plane system based on Myricoms XBAR-8 ICs. Seven XBAR-8 were used to construct a Myrinet network to provide back plane connectivity for the APU and DACU modules (16+16=32) in the system. The configuration constructed is shown in the above diagram. Each port has a data communication bandwidth of 160 Mbytes / Sec. For the system as a whole, the aggregate possible simultaneous inter node bandwidth that could be achieved is 10,240 Mbytes / Sec (10.240 Gbytes/Sec).

A single 25M-1M Myrinet protocol conversion IC was used to interface the SUN development platform to the UVSP system via the Myrinet protocol. The data bandwidth of this link is at 160 Mbytes / Sec.

2.3 MECHANICAL DIAGRAMS

2.3.1 UVSP LAYOUT FIGURE



2.3.2 SUMMARY

The form factor of the UUVSP developmental system consisted of government supplied cylinder shells used to house the electronic components. The shells are approximately 21 inches in diameter.

2.3.2.1 FRONT

The front shell was the HRA component. This section was the sole responsibility of NUWC. This shell section would not have been interface to under the first phase of the developmental program. However, work done in the first phase of the program have allocated necessary design and resource functionality to allow for the integration of this section without modification of prior work.

2.3.2.2 MID

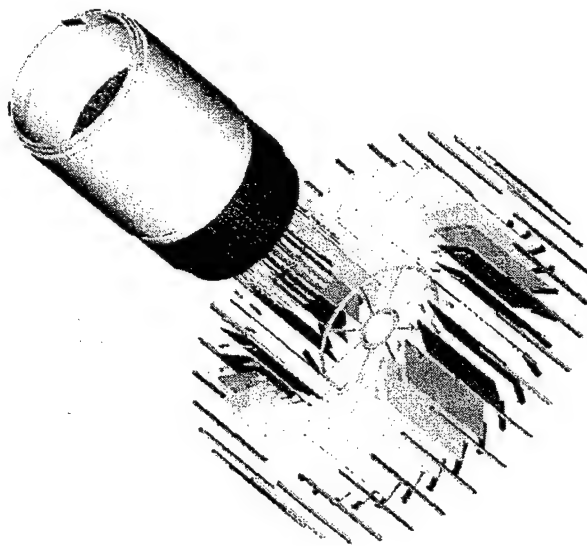
The mid section contained the electronic processing modules (APUs), the DACUs, and the back plane unit. This section was design to hold 16 APU units, 16 DACU units, and 1 back plane unit. This section also allowed for a power cabling harness to be routed from the power section shell (rear) to the HRA unit (front).

2.3.2.3 REAR

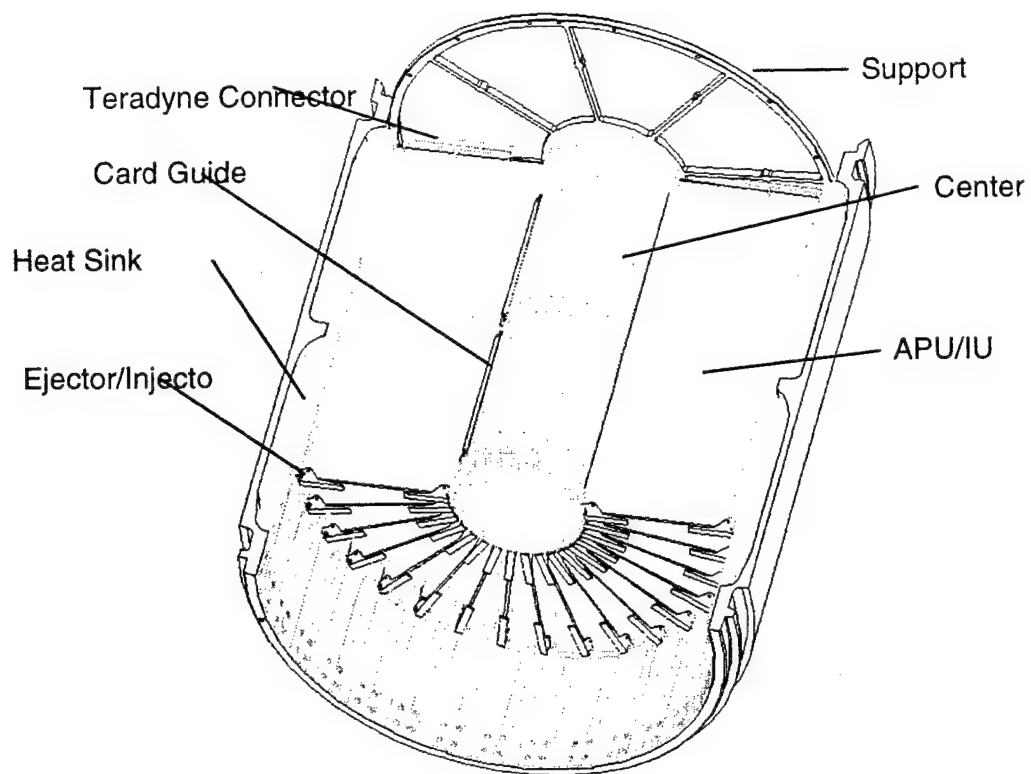
The rear section contained the power conversion units (DC-DC converter modules) and the buffer interface circuit card. All the necessary I/O for a tethered system would interface to this shell section using the buffer interface circuit card.

2.3.3 EXPLODED MID SECTION VIEW

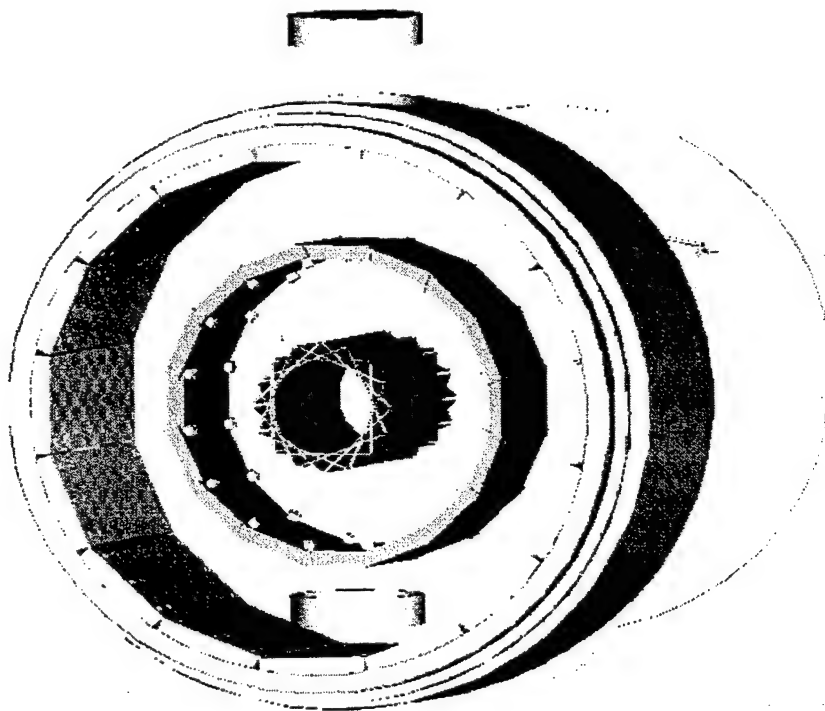
Processor Shell Exploded View



2.3.4 CUT AWAY MID SECTION VIEW



2.3.5 EXPLODED REAR SECTION VIEW



2.4. HARDWARE MODULE STATUS

2.4.1 APU MODULES

2.4.1.1 BUILT

13 APU modules were built and successfully tested at a bench level functional test. Each module was built and tested to operate at clock rate of 40 MHz for the ADSP21060 DSPs.

2.4.1.2 PROBLEMS

No problems of significance were encountered that needs further reporting.

2.4.1.3 NOTES

None.

2.4.1.4 LESSON LEARN

2.4.1.4.1 BUY AVAILABLE PARTS THAT MEET SPECIFICATION OF DESIGN

The APU modules used a CQFP package, heat slug down from Analog Devices. A thermal analysis study was presented and shown at a program meeting, that the lesser grade PQFP commercial parts with heat slug up would have performed within specification in the system.

The CQFP parts slipped in delivery by 5 months as per promised date from Analog Devices. These parts cost an additional \$90,000 (qty=220 pieces) verses the PQFP parts. The slippage of delivery had a cost impact on the program on both software and hardware resources. The hardware lost labor estimate for the slippage is at \$40,000 minimally.

2.4.2 BACK PLANE MODULES

2.4.2.1 BUILT

2 back plane modules were built and tested.

2.4.2.2 PROBLEMS

A ground loop between the SUN workstation Myrinet card and the back plane unit cause bit hit problems during testing. With the proper grounding scheme, this issue was fully corrected to the available test software's (Sunbug) ability to detect errors. A more robust test scheme needs to be implemented to test for data integrity issues of the Myrinet network to determine if this issue still exists.

Sunbug test software has a limited interface to change the data test patterns and packet sizes that are sent through the network. Each test needed the software to be recompiled prior to executing. It was found that during testing that various patterns and data set sizes would cause bit errors in the network. It is concluded that tests need to be expanded to a greater variety of data patterns and packet sizes to test for signal integrity issues.

Sunbug is limited to a "loop back" testing scheme through the port switches. Sunbug does not test the final SAN interface to the LANai. This interface was tested during the APU modules bench level testing, but the test was not extended to the system level test. It is needed during system level testing to verify the source or existence of any signal integrity issues on the Myrinet network that might exist. Test software needs to be extended from a PC based bench software to a SUN based test suite of software that tests this interface on a per node basis. Also, this test software needs to exercise various data patterns and packet sizes as indicated earlier in this section.

2.4.2.3 NOTES

The lack of a more robust test suite for the back plane leaves open the issue that signal integrity problems might still exist with the back plane unit.

2.4.3 POWER SYSTEM

2.4.3.1 BUILT

One aft shell power system was built. The system converts 300 VDC to 3.3 VDC and 1.2 VDC to be used in the embedded applications. The system was tested and is functionally working as a stand-alone.

2.4.3.2 PROBLEMS

No problems of significance were encountered that needs further reporting.

2.4.3.3 NOTE

Since system integration and test did not extend far from bench testing utilizing lab supplies and not the UUVSP developed power system, no significance utilization of the power system occurred. Possible problems might arise if further integration activity occurred.

2.4.4 MONITOR BOX

2.4.4.1 BUILT

One monitor box system was built. The system was tested and is functionally working with the power system, but not as an integrated unit with the APU modules due to the extent of process during system integration and test.

2.4.4.2 PROBLEMS

No problems of significance were encountered that needs further reporting.

2.4.4.3 NOTE

Since system integration and test did not extend far from bench testing to utilize the UUVSP monitor box unit, possible problems might arise if further integration activity occurred.

2.5. SYSTEM STATUS

2.5.1 BUILT

One system based on 13 APU modules.

2.5.1.1 PROBLEMS

Problems during system integration and test could not be corrected with the remaining budget on the UUVSP program.

2.5.1.1.1 SYSTEM INTERGRATION AND TEST PLAN

The integration and test effort executed did not lend itself useful to a debug effort that could localize faults in the hardware (or software). System integration and test used a scaled down operational algorithm to run across 2.5 modules (20 processors). There was no attempt to run a program BIT on the modules in the system to determine a module's health prior to jumping to testing an operational algorithm over twenty processor units.

2.5.1.1.2 TEST SOFTWARE

The HPSC APU module SUN based level test software was never utilized for the UUVSP system. It would have been helpful in accessing and localizing faults in the system. The SUN based software from the HPSC effort should be the first step in the system test and integration phase if this program is extended. This software would be most helpful in localizing faults in the hardware and/or software.

3. ALGORITHM AND SOFTWARE DEVELOPMENT (CDRL A009)

The UUV software development environment was SUN Workstations, and Personal Computer (PC) Windows 3.1, 95 (for the bootstrap loader). ADI software development software (hosted on the SUN, and the PC) was used to develop the SHARC software. Wideband Computers Inc. ADSP-21K Optimized DSP Library was used to provide the hand optimized functions needed in the bathymetric algorithm.

The UUV software content consisted of:

- Bathymetric Processing Unit (BPU) software
- Interface Unit (IU) Software
- Operator Console (SUN SPARC Station), with the SUN support software.
- Common to the BPU and the IU was the Bootstrap Loader, and support tools modifications (this software is PC based).
- Common to the BPU, IU, and the SUN station were the LANAI Distributed Architecture Resource Controller (DARC) modifications.

The UUV software system first loads each processor in each node with the operator-specified software. This includes the 4 IU nodes, and up to 48 BPU nodes. The operator then specifies configuration data, sample data, and operating mode. The SUN based software formats the selected data into messages that were transmitted to the IU. The IU then disseminates this information to the BPU's. The results of the BPU's are transmitted to the IU, where the magnitudes of each angular bin of each azimuth angle compare from each BPU (48 - 1 data reduction). This result is transmitted to the operator console.

Figure 1 shows how the information was disseminated amongst the various software elements during bathymetric operations.

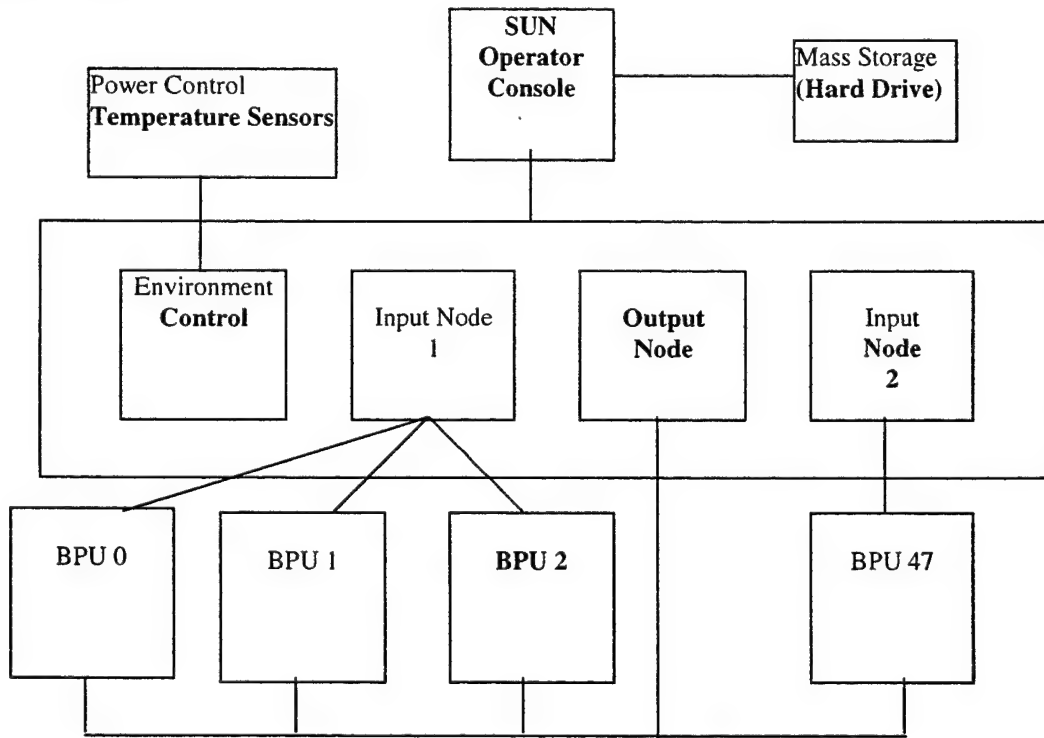


Figure 1- Software Breakdown

3.1 UUV Interface Unit (IU) Software

The IU performs 3 function the UUV system. First it provides the environmental control for power management and leak detection. Second it simulates the sensor front end. Third, the IU acts as the output unit to reduce the peak results collected from each BPU to a reportable peak results (a 48 – 1 data reduction).

To achieve the environmental control the IU software initializes serial port 0, node 1, processor 1. Using serial port 0 it can read 192 potential temperature sensors, control the secondary power converters supplying power the BPU's, HRA's, and DACU's. It is capable of resetting the APU's and the DACU's. It can also check the status of the power system. The control of this function is message driven under operator command, with the results being transmitted as a message back to the operator to be displayed on the operator console. Because of hardware limitations affecting the serial port, this function couldn't be fully tested.

To simulate the sensor front end the IU used nodes 2 and 4. This was chosen because of the Myrinet connectivity, thus minimizing routing conflicts. The "Input Nodes" each were responsible for transmitting the sample data to ½ of the configured BPU's. A timer was used to simulate the sampling rate (10875 Hz) of the sensor front end. The software would DMA the sample data from the input queue (in DRAM), into SHARC SRAM, then DMA the sample data to the output queue(also in DRAM). When the timer event occurred, the transmit command would occur. This software had to keep track of the number of frames sent and determine when to set the end of ping flag in the sample data message. The Input nodes had to have a flow control for when the UUV system was the continuous operation mode. This was necessitated because the BPU's took ~ 2 seconds to process a 1 second ping. This required the output node to send a message via Myrinet to the 2 input nodes once the IU output node had received the peak results from the all of the BPU's. The flow control for continuous processing was implemented, but not tested.

The third function that the IU performed was to reduce the results produced from the 48 BPU's to 1 reportable result, a 48 to 1 reduction of data. The 3rd node of the IU performed this function using all 4 processors. After reduction, the results were transmitted to the SUN operator console for storage/comparison/display.

3.2 UUV Bootstrap Loader/Tools Software

The UUV bootstrap loader was designed primarily under HPSC. Modifications had to be done to boot without the use of the "Root Node", and to the Prom loader routine due to the changes to the link port connectivity. This required changing the support tools associated with the bootstrap loader. These support tools were used to burn the bootstrap loader into the flash ROM.

3.3 UUV Bathymetric Software

The bathymetric software responds to 3 type of messages received:

- Initial Parameters Message
- Sample Data messages
- DAP Header messages

And transmitted to the IU output node, the results of the bathymetric algorithm in the peak results message

The initial parameter message initializes:

- the number of BPU nodes
- the frame frequency
- the number of angular bins
- the azimuth start angle
- the azimuth angle increment
- the number of azimuth angles (This must be a multiple of 4)
- speed of sound
- array element spacing

- sensor gain

The initial parameter message would be received once with the above parameters. The software would use these parameters to allocate memory buffers, and initialize parameters needed in the bathymetric algorithm. This message should not be used in real time, since data buffers are deallocated and reallocated.

The DAP header message initializes:

- number of frames per ping
- receive gate delay
- the D/A trigger delay
- the transmit frequency
- the decimation rate
- the time vs. gain table

The DAP header parameters were created when the sample data was collected. Some of these parameters are used to allocate data buffers, and to initialize parameters needed in the bathymetric algorithm. As in the initial parameter message, this message is not intended for real time. If the system selected was single ping mode, the DAP header message would be sent out for every sample sent. If the system was in continuous mode, the DAP header message would only be sent once. It would be assumed that to change the DAP parameters would require a change to the DAP mode, thus stopping sample operations while this change was in progress.

The Sample Data message contains

- end of ping flag
- 512 packed 16 bit integer In-phase and Quadrature (I,Q) pairs (i.e. 1 frame of sample data)

Each ping contains 10875 (default value) frames of sample data. The default number of BPU's is 48, thus each BPU processes ~227 frames of data. The detection of end of ping flag in the sample data message caused the transmission of the Peak results message to the IU. Each frame calculation would compare the magnitude calculated with the previous maximum magnitude for that azimuth and angular bin, saving the greater magnitude, with the associated frame and angle.

The Peak Results Message transmitted from the BPU to the IU contains [number of azimuths][number of angular bins] - the number of azimuths (40 default), and the number of angular bins (255 default).

- frame data
- angle
- magnitude

Timings were done on the bathymetric algorithm using 4 nodes, and the HPSC APU's. Expand this timing to 48 UUV APU nodes, with the currently implemented bathymetric algorithm, a 1 second ping would be processed in ~1.97 -2.0 seconds.

3.4. UUV Operator Console Software

The SUN based operator console provided a Graphical User Interface (GUI) (designed using X Designer) which the operator could control the operation of the UUV system. The GUI selected/sent the initialization parameters, the DAP header parameters, and the sample data. The operator could also request/view the UUV temperature status, the power status, and select the operating mode (Single Ping/Continuous operation). The GUI also downloaded the UUV software to the IU, BPU's, and LANai's. The SUN software was also able to read network configuration files to be able to generation the routing parameter tables, and the message parameter tables for the UUV system.

3.5. LANAI Distributed Architecture Resource Controller (DARC) modifications

The DARC was originally implemented using 256K 32bit words of SRAM. In the UUV design, only 128K 32bit words of SRAM were used. This required that the DARC have modifications done so that memory-

mapped variables could have their addresses change. The decision was made to use a configuration header file that defined all the addresses of importance. This then allowed all future customers that ability to customize their memory requirements. This proved usefully when the SBUS card in the SUN station providing the 25M Myrinet communicated was upgraded from 128K bytes to a 512K bytes. The same configuration file was used in the SUN DARC thus requiring only minor changes.

3.6. Lessons Learned

Porting the bathymetric algorithm was the trivial part of the software job. Controlling the data messages is the key to scaleable computing. For sensor applications, the communication protocol must be able to send data continuously with minimal overhead. At the start of software development, the only available Myrinet Control Program (MCP) was the Data Synchronization Queue (DSQ). For this reason, DSQ's were used in the UUV software. A lesson learned was not to rely on immature technology. The MCP used was not a mature technology. The personnel responsible for this technology had persuaded other professional opportunities. The above, was also true of the bootstrap loader/tools software. This required the UUV software team to spend time debugging/learning these technologies. It should also be noted that because these technologies are leading edge/immature, the tools needed to debug them are immature.

The Total View debugger was used to debug the SHARC based software. This made possible debugging multiple SHARCs, on multiple nodes in real time. This was a significant improvement over existing debuggers. The Total View operated on a Sun workstation with the 25M SBU'S Myrinet card. It used the HPSC DARC for its MCP. This tool, though immature, greatly enhanced the ability to debug scaleable computing solutions on the SHARC.

The Math library used on UUV was Wideband Computers Inc. ADSP-21K Optimized DSP Library. It's \$1500.00 price tag, with no run-time licensing fee is good. The company gives excellent service after the sale without hassles. This library performed well for the UUV project.

The ADI software development tools (3.2/3.3) are poor. The compiler has bugs. The linker/simulator (3.2/3.3) doesn't support the multiprocessor memory space. The prom loader (3.2) only worked for processor ID 0, (the Root Node for HPSC APU's. UUV APU's don't have a root node). This requires UUV personnel to debug ADI's software. This then required UUV to upgrade to version 3.3. ADI has released (01-Jun-98), for the PC, Visual DSP.

The biggest problem affecting UUV software was the inability to transmit and receive sample data reliable. Data packets would become corrupt, get dropped, thus preventing the system from operating. More effort is needed to develop testing methods to identify potential hardware/software problems associated with large-scale data movement.

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